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Reconstruction and Identification of Hadronic Tau Decays with ATLAS

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The presence of τ leptons in the final state is an important signature in many Higgs boson and SUSY searches. With the ATLAS detector, hadronically decaying τ leptons can be reconstructed in a wide range of transverse energies. The reconstruction algorithm for hadronically decaying τ leptons is explained and the performance of τ lepton identification is shown. Particularly important is the discrimination of hadronically decaying τ leptons against overwhelming backgrounds from QCD jets.

1. INTRODUCTION

The τ lepton, with a mass of 1776.84 ± 0.17 MeV [1], is the only lepton heavy enough to decay both leptonically and hadronically. It decays approximately 65% of the time to one or more hadrons. The reconstruction and identification of τ leptons are important in many searches for new phenomena, and they can appear in final states during the production of Higgs bosons or supersymmetric particles [2]. This paper will discuss the reconstruction and identification of hadronically decaying τ leptons with the ATLAS detector [3].

2. RECONSTRUCTION OF HADRONICALLY DECAYING τ LEPTONS

Hadronically decaying τ candidates are reconstructed using at least one of two possible seed types. The first seed type is a track with $p_T > 6$ GeV. This leading track must satisfy further quality criteria to be considered a valid seed for a τ candidate.

The second type of seed consists of jets reconstructed using topological clusters (topoclusters) [2] with $E_T > 10$ GeV. Topoclusters are formed using cells that exceed calorimeter noise by 4σ, and neighbouring cells that exceed energy thresholds above calorimeter noise by 2σ and 0σ are associated to the cluster in a second and third step, respectively. These topoclusters are then grouped into a topojet using a seeded cone algorithm [4] with a cone radius of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$ which form the aforementioned seeds for τ candidates. These topojets are then matched to seed tracks in a cone of radius $\Delta R = 0.2$ around the topojet. If such a match is found, the τ candidate is considered as having two valid seeds. For reconstructed τ leptons in $Z \to \tau\tau$ events, 70% of τ candidates have two valid seeds, 25% have only a topojet seed, and 5% have only a track seed.

The energy of the τ candidate is calculated in two ways. For τ candidates with a topojet seed, the cells in a cone of $\Delta R = 0.4$ are summed and weighted using a calibration similar to that used for the Liquid Argon calorimeter of the H1 experiment [5]. Scale factors, determined from Monte Carlo and depending on the p_T and η of the τ candidate, are used to further correct the energy scale.

For τ candidates with a track seed, an energy flow approach is used, where energy deposits in cells matched to charged tracks are subtracted and replaced by the momenta of such tracks. This energy of the τ candidate is also corrected for energy leakage coming from charged particles outside the narrow cone.

Tracks associated to the τ candidate in a cone of $\Delta R = 0.2$ are required to pass track quality criteria, albeit less stringent than those for the leading track. Figure 1 (left) shows the track multiplicity distribution for τ candidates matched to true hadronically decaying τ leptons. Topoclusters found in the electromagnetic (EM) calorimeter with $E_T > 1$ GeV that are isolated from tracks are interpreted as energy deposits from π^0 mesons in the τ lepton decay.

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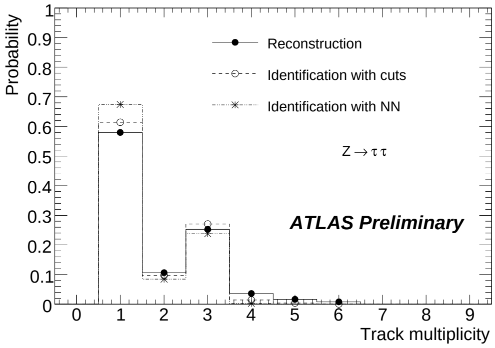

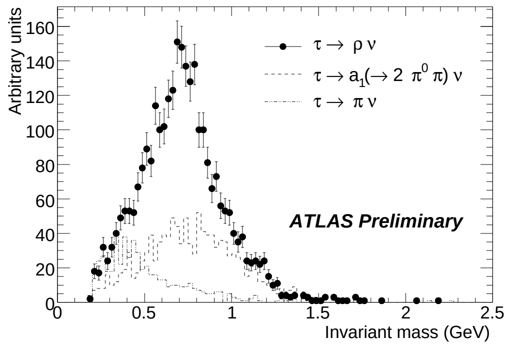

Figure 1: Left: Track multiplicity for τ candidates in $Z \to \tau\tau$ events after reconstruction and identification steps. Right: Reconstructed invariant mass distribution for $\tau \to \pi\nu$, $\tau \to \rho\nu$, $\tau \to a_1\nu$ decays in $W \to \tau\nu$ events.

We find that approximately 66% of $\tau \to \pi\nu$ decays are reconstructed with zero π^0 subclusters, while more than 50% of $\tau \to \rho\nu$ ($\tau \to a_1\nu$) decays are reconstructed with one (two) π^0 subcluster(s).

Based on the calorimeter information, the associated tracks and reconstructed π^0 clusters, a variety of other variables are calculated to be used for the identification of τ leptons. These variables include the radius of the τ candidate in the EM calorimeter, isolation variables for the calorimeter energy and tracks, reconstructed charge (based on the associated tracks), and the invariant mass of the τ candidate. The invariant mass distribution for selected τ candidates based on the above mentioned variables is shown in Figure 1 (right).

3. IDENTIFICATION METHODS FOR τ LEPTONS

Because of the large production cross section for QCD jets, identification methods are needed to discriminate τ candidates arising from true τ lepton decay and those from QCD processes. Identification methods are also used to distinguish hadronically decaying τ leptons from electrons and muons. At ATLAS, various identification methods have been studied, ranging from simple cut-based criteria, to multivariate techniques such as: projective likelihoods (LH), boosted decision trees, neural networks, and probabilty range searches. Here, only cut-based vetoes against muons and electrons and the projective likelihood discriminant against QCD jets will be discussed.

Muons are vetoed by requiring that the calorimetric energy deposited by the τ candidate has $E_T > 5$ GeV. For electrons, cuts are placed upon 1-prong τ candidates on the following two quantities: the ratio of the transverse energy deposited in the EM calorimeter to the track transverse momentum which tends to be higher for electrons than for charged hadrons, and the ratio of high threshold hits to low threshold hits in the Transition Radiation Tracker for the track, which also tends to be higher for electrons. This veto suppresses electrons from $W \to e\nu$ events by a factor of 60, while retaining a 95% efficiency for τ leptons in $W \to \tau^{had}\nu$.

Discriminating variables used to distinguish τ leptons from QCD jets include: radius and profile of EM calorimeter energy deposits, track width distributions, isolation variables calculated from calorimetric energy deposits and tracks, impact parameter significance of the leading track, invariant mass of the associated tracks, ratios of energy deposits to the sum of track transverse momenta, and the transverse flight path significance of the τ candidate vertex. Sample distributions of a subset of these variables are shown in Figure 2.

The LH takes these variables and forms probability distribution functions (PDFs) for τ leptons (signal) and jets (background), which are separated into the following categories: the p_T of the τ candidate, the number of associated tracks, valid seed types, and the presence of π^0 subclusters. A likelihood ratio is formed using the product of individual likelihood ratios for the signal and background hypothesis in each variable. The performance of the LH is shown in Figure 3 for 1-prong and 3-prong τ candidates. For τ candidates with $30 < E_T < 60$ GeV, a 40% τ identification efficiency corresponds to a QCD jet rejection of 1500 ± 100 (1480 ± 100) for 1-prong (3-prong) candidates.

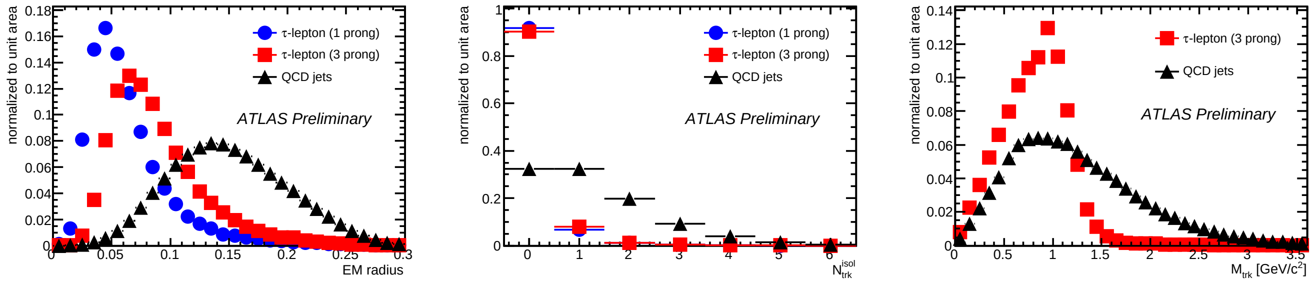

Figure 2: Distributions of selected identification variables for 1-prong τ leptons, 3-prong τ leptons, and QCD jets.

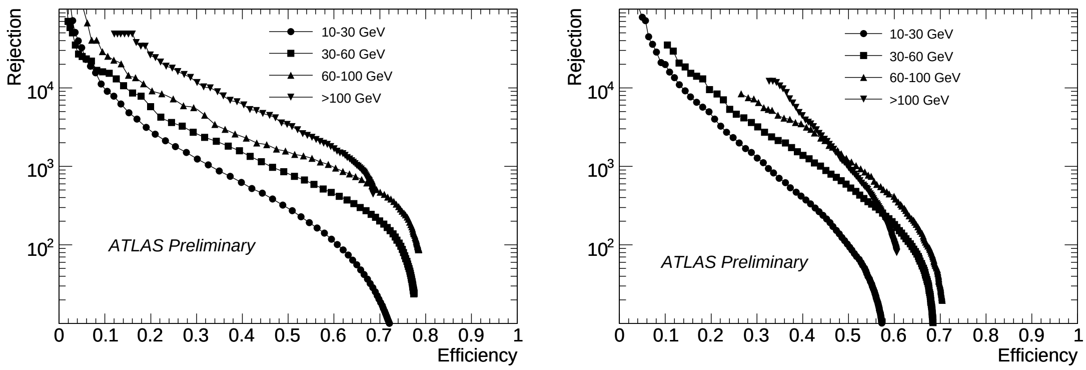

Figure 3: Left: QCD jet rejection as a function of 1-prong τ efficiency for the projective likelihood discriminant. Right: QCD jet rejection as a function of 3-prong τ efficiency for the projective likleihood discriminant.

4. CONCLUSIONS AND OUTLOOK

ATLAS is planning an extensive program to investigate physics channels with hadronically decaying τ leptons in the final state. Sensitivity to such channels requires robust reconstruction algorithms and well performing identification methods to distinguish true τ leptons from QCD jets, electrons, and muons. Studies for extracting cross sections for Standard Model processes such as W, Z, and $t\bar{t}$ production with hadronic τ leptons in the final state have been performed [2]. An understanding of these Standard Model processes will aid the understanding of searches for new physical phenomena with final state τ leptons.

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